Optimized Adaptive Type – II Polar Fuzzy Automatic Generation Control for Deregulated Power System

Synopsis

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Introduction

Electrical Energy is an instant resource. Production and consumption of electrical energy happen instantaneously, and large quantities cannot be profitably stored. People had to buy it from vertically integrated utilities. The term "vertically integrated utility" (VIU) is commonly used to describe power systems. The purpose of VIU is to allow a single system operator to oversee all generating, transmission, and distribution activities within a specific topology. The system aims to give customers reliable power at a reasonable price with consistent voltage and frequency. It was governed by government regulating authority based on the actual cost to guarantee dependability and total affordability. It is necessary to regulate the transmission system's open-access participants. As a result, the regulator's role is crucial and ought to be handled independently. The ultimate authority for maintaining dependability and controlling system parameters like voltage and frequency within acceptable bounds is an Independent System Operator (ISO). The ISO purchases and charges fair prices by coordinating the participants. Figure 1 depicts the VIU structure of power system. At first, an electric corporation controlled a sizable utility, acting as the central authority for electricity production, distribution, and transmission. The VIU could not separate the generation, transmission, and distribution energy rates. As a result, it is derived from the consumer as a mean expense (tariff) based on their cumulative rate throughout time. Money is designed to flow from consumer to the distribution company. Similarly, the pathways via which data flows from generation to transmission systems.

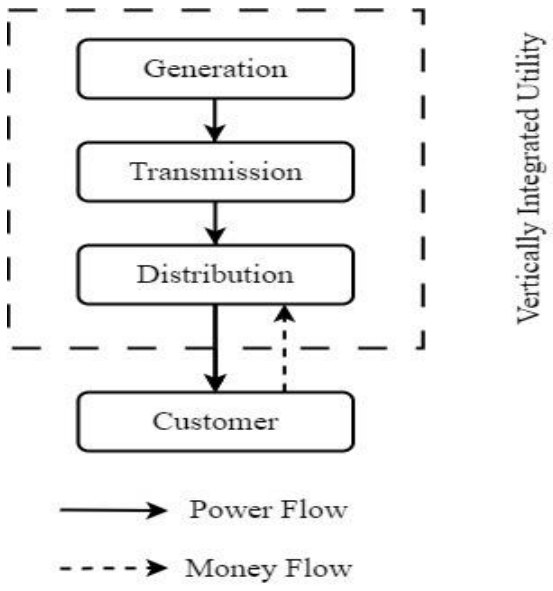

Fig. 1 Traditional VIU Power System [DJ 24]

The VIU power systems have the following features:

(i) The local electric utility is the only one that produces, sells, and provides power service to customers within its service area.

(ii) The utility alone must service every customer within its area.

(iii) The government regulatory authority sets the standards and norms to which all technical procedures and commercial functions must adhere. The government's guidelines and regulations must be followed when setting the utility tariffs.

Due to the electrical sector's liberalization, numerous independent power producers (IPP) can now connect to the transmission network. Electricity sellers (producers) and purchasers (dealers/customers) must share a standard transmission network to transport electricity from the production point to the location of utilization. As a result, an interlinked transmission network is regarded as a natural monopoly to avoid duplication, right-of-way issues, and significant investments in the latest structures. It also benefits from an interconnected network's lower installed capacity, higher system reliability, and better system performance. The power flow patterns in the current regulated system are expected to be different in a deregulated environment. Specific transmission channels may become overloaded and congested as everyone seeks reduced costs and larger profit margins. This may surpass the limitations imposed by stability, voltage, and heat. Some players may also take advantage of system limitations to further their dominance in the market. Therefore, to guarantee that all market participants can freely and openly utilize the transmission network, a System Operator (SO) is needed to supervise its management, security, and dependability. The energy sector reform has altered the roles of the old VIUs while new, independent businesses have formed.

Generation Corporations (GENCOs), Transmission Corporations (TRANSCOs), and Distribution Corporations (DISCOs) are the autonomous entities in a deregulated electricity structure. The power will be transported by TRANSCOs between GENCOs and DISCOs. The GENCOs, TRANSCOs, and DISCOs connected to the executed contracts are enclosed in a control area. Any variation in frequency accompanied by an abrupt load perturbation in a real-time power market can immediately impact the dependability and efficiency of the power system. Vibrations from excessively low system frequencies have the potential to harm steam turbines. Automatic Generation Control (AGC) is essential to designing

and maintaining the unregulated electricity structure. It reduces fluctuations in frequency and controls tie-line energy. Area control error (ACE) (i.e. the combined effect of frequency deviation and tie-line energy) is the foundation of AGC.

GENCOs may or may not engage in the AGC task. The term "poolco transactions" refers to contractual arrangements by a DISCO with GENCOs or IPPs within the same control area. While "bilateral transactions" refer to agreements that DISCOs make with any GENCOs or IPPs in their own or another region. If DISCOs want additional power, they may breach the terms of the contract. This excess power is known as an uncontracted demand or contract violation. Through an ISO, every transaction must clear. Based on the market framework put in place, AGC/LFC programs in most developed nations differ from one country to the next following the deregulation of the electrical market. The information requirements of vertically integrated units, as well as contracted data information, will be met by AGC schemes. AGC is a crucial ancillary service to ensure the dependable operation of the deregulated power system in this context.

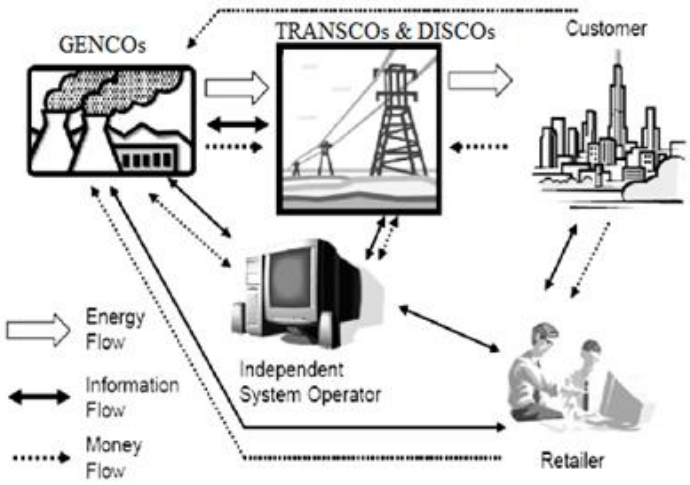

Fig. 2 Deregulated Power System [RJ 23]

Disco Participation Matrix (DPM)

GENCOs distribute power to different DISCOs at competitive prices in the deregulated market. As a result, DISCOs are free to select which GENCOs to hire. Contracts with the GENCOs in their locality may or may not be in place. As a result, different GENCO-DISCO contract combinations are feasible in actuality. The DPM matrix comprises rows corresponding to the number of GENCOs and columns corresponding to the number of DISCOs inside the system.

$$\begin{pmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & \alpha_{14} \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & \alpha_{24} \\ \alpha_{31} & \alpha_{32} & \alpha_{33} & \alpha_{34} \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & \alpha_{44} \\ \alpha_{51} & \alpha_{52} & \alpha_{53} & \alpha_{54} \\ \alpha_{61} & \alpha_{62} & \alpha_{63} & \alpha_{64} \end{pmatrix} \quad (1)$$

Each element in equation (1) can be regarded as a fraction of the total load allocated by a DISCO (column) to a GENCO (row). The ij-th entry represents the proportion of the total load power contracted by DISCO j from GENCO i. The aggregate of all entries in a column of this matrix equals one. The DPM illustrates the involvement of a DISCO in a contract with a GENCO, hence presenting the "DISCO participation matrix." In equation (1), αij denotes the "contract participation factor."

Since there are numerous GENCOs in each area, the ACE signal distribution must consider their level of AGC participation. "ACE participation factors" are coefficients that assign ACE to several GENCOs.

$$\sum_{j=1}^{ni} apf_{ji} = 1 \quad (2)$$

Power Transaction

It is possible for GENCOs and DISCOs to transact power in a number of contracted ways in deregulated power networks. In the same control region, a DISCO is free to enter into agreements with GENCOs for the transfer of power. The phrase "Poolco-based transaction" refers to this type of transaction. GENCOs in another control area may be the subject of contracts with a DISCO. A bilateral transaction is what it is termed. Contracts for mutual cooperation are negotiated by the GENCOs and DISCOs. Each transaction must go via an ISO after their contractual agreements have been presented to the ISO. GENCOs thereafter sell power to DISCOs at fair prices.

Literature Review

Since their inception, the electric power industries have seen numerous structure and operation modifications, as well as developments in domains such as control. The transition from a regulated to a deregulated environment is one of the greatest fundamental shifts in the management and functioning of the electrical network. The control processes have been updated to adapt to the altered power

situation. Despite their proven effectiveness in governing large, complex, restructured power systems over more than 20 years, AGC approaches have found a quiet place in the literature. The literature in this field has examined the following DPS characteristics:

As the power industry transitions from regulated to deregulated status, the AGC's conventional operating procedures must be adjusted to align with its requirements in the current operational setting. An unregulated atmosphere transforms the AGC into an asset for trading. GENCOs that participate in the AGC are required to receive compensation for the service they provide. In an environment of competition, AGC is critical to ensuring system dependability.

Numerous studies conducted in recent decades have advanced our understanding of AGC in the unregulated electric market. The early research supports the work of Rudnick et al. [HR 97], Bakken and Grande [BHB 98], Kothari et al. [MLK 98], Meliopoulos et al. [APSM 99], and Donde et al. [VD 01]. Liu et al. [FL 03] presented a paradigm for handling optimal LFC challenges in a reorganized system. Additionally, Bevrani et al. [YHB 05], Ansarian et al. [MA 06], and Hausman et al. [EH 08] all modified the conventional AGC system and showed how bilateral contracts impact AGC systems. Tyagi and Srivastava [BT 06] used the DPS state space model to illustrate a distributed state feedback regulator with Eigen structure allocation.

Most research in the literature concentrates on thermal plants (although accounting for different types of turbines), which needs to adequately capture the actual scope of AGC problems in a deregulated setting. Furthermore, researchers have proposed several unregulated AGC concepts and arrangements for steam, hydroelectricity, and gas power stations. Rahman et al. [AR 15], Ponnusamy et al. [MP 15], and Kumar et al. [NK 16] have all looked at two-area hydrothermal deregulated AGC systems. In their study [RKS 15], Sahu et al. investigated two-area hydrothermal recognized AGC frameworks with GRC and time delay that used AC/DC connections. Gorripotu et al. [TSG 15] propose a two-area hydrothermal unregulated system that uses RFB and IPFC, GRC, and time delay. Shiva and Mukherjee [CKS 15] and Shree and Kamraj [SBS 14] claim to have researched three-region steam-hydroelectricity-gas-based AGC structures, either with or without GRC. In a different paper, Shiva and Mukherjee [CKS 16] examined unrestricted 5-region steam-hydroelectricity-gas structures with governor dead band, time delay, and GRC.

Researchers have studied and addressed a range of complex control mechanisms to improve system performance. Furthermore, a few studies have examined the effects of FACTS unit operation and coordinated energy storage devices in multi-area deregulated electricity networks. These systems are becoming more complex because nonconventional source power stations are participating more actively in interlinked electricity networks. Recognized electrical networks include electric stations that use gas, hydro, thermal, and renewable energy sources.

AGC Strategies

The literature review cites the following examples of AGC tactics:

1. Conventional Control Strategies

Jaleeli et al. [OJ 92] and Elgerd and Fosha [OIE 70] introduced the idea of traditional AGC. Christie and Bose [RDC 96] have discussed LFC concerns about the recognized electrical grid. In [BHB 98], Bakken and Grande developed a controller that follows a ramp. Two different AGC solutions have been put up regarding the deregulated systems in Sweden and Norway. Abraham et al. [RJA 15] examined the standard AGC of a two-region power station and made a few changes to mitigate the impact of bilateral transactions. Kothari et al. [MLK 98] published a feasible AGC modeling for a two-region steam structure utilizing the ISE technique. They discovered the optimal bias and integral gain settings, illustrating the results of various contracts in a deregulated environment.

A typical PI controller performs poorly in real-world scenarios. To improve further, a model-matching controlling technique is used to optimize the K_{pi} and K_{Ii} for AGC of a two-region reheat hydrothermal structure [GV 13]. The literature explains creating a multi-solution wavelet controller in a deregulated environment to solve the multi-area power system's LFC problem. Its responsiveness is superior to a conventional PI controller [AGDK 16]. In actuality, there are no linear systems. All realistic systems have some nonlinearity. The dynamical system has two distinct forms of nonlinear characteristics: intermittent and continuing nonlinear behavior.

An excellent example of continuous nonlinearity is the gravitational force acting on a pendulum. Examples of intermittent nonlinear properties include delay, backlash/hysteresis, saturation, dead zone, and so on. [DKC 10]. In [NH 12], linearized AGC methods for multi-region reorganized structures are

proposed. The writers have carefully considered the effect of network nonlinear properties. The studies investigated the consequences of GRCs. [PR 10, NFG 12]. When an optimized PI controller with ICA is used for two-region nonlinear DPS (the valve movement limit is not linear), the results are better than when an un-optimized PI controller is used [MKD 16]. Hou et al. describe a T-S model for producing a nonlinear valve position constraint. The ACS technique was devised to regulate an integral controller's parameters for resolving LFC challenges in two-region DPS to solve true-valued arithmetic-optimized difficulties [SRK 14]. The pseudo-code for the ACS algorithm is explained in [PC 13]. Debbarma et al. proposed the FOPID regulator for the AGC of the multi-region reheating steam plant. Parmar et al. [KPSP 14] presented an altered LFC method for multi-source modules. It practically approaches the optimum output feedback regulator. This covers all potential energy exchanges.

Additional complexity and implementation costs are associated with reconstruction, and obtaining all state variables for measurements in a practical situation is only sometimes possible. Sadeh et al. [JS 08] employed only quantifiable state variables within every controlling sector to provide feedback. The output feedback technique can help monitor contractual and non-contracted demands. In another research project, the model-matching method is used to develop a reduced-order controller. Generator owners determine the economic participation component, pace of change, and generation constraints for each unit that submits to the LFC. It is sent to the ISO in this format. ISO accomplishes the LFC purpose in a primarily regulatory environment. This method is adaptable, according to Meliopoulos et al. [APSM 99].

After reorganization, Rakhshani et al. [ER 10] enhanced the multi-region structure's dynamic responses by creating reduced-order observable approaches and optimum output response. In contrast to previous approaches, the reduced-order observing regulator satisfies the LFC requirements [ER 08]. Daneshfar et al. attempted to optimize the PI variables for regulators for a three-region network under the bilateral policy scheme. This method is highly efficient and easier to install than more conventional and sturdy controllers. To satisfy the contract's stipulated demand, Reference [GHR 16] constructed a load frequency controller in a multi-source, multi-region DPS.

Furthermore, Liu et al. suggested a quasi-Newton structure strategy for optimizing LFC in DPS [FL 03, FL 02]. The gradient Newton technique was established by Donde et al. [YHB 05] to study the optimal

way to govern the unregulated AGC system. Improving transient reactions is the main objective of optimizing. Another study used the complete state feedback regulation approach to design the best AGC controller for a two-region DPS, as reported in [NH 12]. We looked for patterns in closed-loop eigenvalues to gauge the system's stability. Reference [DRA 15] discusses the best way to regulate LFC in a two-region, non-reheat steam structure. Reference [PC 17] compares the AGC of two-region reconstructed electric energy networks with AC and AC-DC linkages. There is thermal-hydroelectricity in every area. All market contracts are modeled using the optimal PI-structured controller and the state space model of power systems. Power systems with and without AC/DC links for stability are compared using eigenvalue analysis.

Moreover, using AC and AC-DC linkages is instrumental in achieving dynamic reactions. Systems with AC-DC links demonstrate significantly enhanced dynamic operation, particularly under diverse market scenarios. An ideal controller in these systems effectively balances power generation and consumption. After developing an efficient AGC controller for hydro-thermal systems with AC-DC linkages, Yogendra et al. [YA 19] discovered that these systems exhibit less dynamic responses than thermal-thermal systems. This underscores the dynamic advantages of AC-DC linkages and their potential to optimize power generation and consumption.

2. Soft Computing/Artificial Intelligence Control Strategies

Researchers have been increasingly interested in applying soft computing-based techniques to address conventional PI and PID controllers' delayed and ineffective handling of system nonlinearities. These methods demonstrate robustness against severe parametric limitations in the power system and higher degrees of load disturbance while providing a better response regarding peak overshoot, settling time, and steady-state inaccuracy. Their practicality in dealing with complicated, unpredictable, and nonlinear technological problems and their affordability and certainty of success further underscore their potential in power system control [OM 22]. S. Ajitha Priyadarsini et al. [SAP 17] examined how the suggested system beats the current/traditional methods by contrasting the Integral, non-tuned Fuzzy Reasoning controller with the GA-tuned FLC. Gaurav Singh Kamboj et al. [GSK 15] work involved two interconnected hydrothermal power areas: a reheat-type engine in the steam region and a low-head engine in the hydroelectric region G. T. Chandra Sekhar et al. [GTCS 16]. Propose a novel FA

optimizing hybrid fuzzy PIDF for LFC of multi region multi-source systems in reorganized surroundings, accounting for physical limitations such as Governor Dead Band (GDB) nonlinearity and Generation Rate Constraint (GRC). Nagendra Kumar et al. [NR 18] examine a multiregion hydroelectric steam 75-bus electrical network as a test structure for the unregulated AGC strategy. To create a secondary controller for two realistic load frequency control (LFC) issue models, Meysam Gheisarnejad [MG 18] proposes a hybrid algorithm called harmony search (HSCOA), which combines the HSA with the COA's immigration and egg-laying mechanisms. The researcher also studies the effect of nonlinearity as a realistic situation on power systems operation by considering GDB. One of the power system's nonlinear problems is optimal power flow (OPF). To address this problem, Ashish Saini et al. [AS 06] proposed a revolutionary GA-Fuzzy-based method. Three area thermal-hydro-wind interconnected power generating systems were proposed to use PID and FOPID controllers as secondary controllers by Mohamed et al. [MAEM 23]. Muntasir A. Magzoubet et al. [MAM 22] suggested an effective mixed PID–-vague AGC built on the simulated annealing regulator approach in place of a traditional regulator for a two-region interlinked electrical network.

In a distinct work, a polar fuzzy logic controller was built and evaluated on a single area and two areas of a thermal system by Rahul Umrao et al. [RU 11]. Gaurav Pratap Rana et al. [GPR 12] used polar fuzzy controllers (PFCs) to build the AGC for a nonlinear, unregulated hydroelectric steam power station. A PFC aims to retrieve frequency and tie-line power to its original state as fast and with as little computational effort as possible. Furthermore, Chaturvedi et al. [DKC 15] have proposed an adaptable PFC-based LFC for a three-region system. The PFC was modified using a GA-fuzzy technique.

D.K. Chaturvedi et al. [DKC 99] designed a non-linear NN regulator utilizing a GNN. The controller controls a power system's load frequency variations via a generalized neuron structure that overcomes neural network disadvantages. Haiguo Tang et al. [HT 19] proposed deep neural network predictive controllers (DNNPCs) control load frequency in interlinked distribution systems. The suggested approach keeps load frequency and connection power steady-state errors within a range. Nehal Patel et al. [NP 13] used generation rate constraints (GRC) and artificial neural networks to create a control line for an interlinked 3-region steam-steam-steam power station. In a three-region interlinked electrical network with two steam engines, an ANN regulator controls the inputs of every region. An ANN method

was presented by Sadeq D. Al-Majidi et al. [SDAM 22] for creating the ideal LFC. However, training an ideal model of an ANN for a multi-region PSN is a substantial challenge due to the variations in load demand. To solve this problem, the first neurons of the ANN model are optimized, and the nodes of a hidden layer are distributed using a particle swarm optimization technique, which lowers the ANN model's mean square error. The outcome shows that compared to the multi-region PSN and the single-region PSN, the LFC relying on the optimum ANN is more efficient at adjusting the frequency level and improving the transfer of power.

3. Deregulated AGC Strategies with Renewable Energy Resources and Electric Vehicles Incorporating Energy Storage Technologies (EST), FACTS Devices

Numerous studies have examined the potential for energy storage devices such as CES, HES, RFB, BEES, and SMES somewhat to mitigate an instantaneous mismatch between power supply and demand. A HES is frequently used to improve DPS power quality. Locating these devices in the best locations in each area might be challenging. RFB appears to react swiftly to unforeseen variations in load in the control zones because of its meager time constant. [RNM 20, PKI 05] covers SMES unit modeling. When the need for electricity in a control region unexpectedly grew, the SMES unit quickly released stored energy. When the governor begins to work under the new equilibrium state, the SMES restores energy to its original state in response to an unexpected decrease in load demand [PKI 05]. Consequently, applying SMES units may effectively lessen power system oscillations brought on by sudden variations in load. Prototypes of battery energy storage systems (BESS) are frequently utilized in power systems for network connection, dynamic filtering, load stabilizing, urgent supply, and reducing inter-region fluctuations [AP 16].

The FACTS devices are essential for controlling traffic, boosting voltage stability, boosting power transfer efficiency, and guaranteeing security. The scientific and financial benefits of FACTS equipment, as well as their effects on DPSs, are documented in [RNM 20]. Kaleem Ullah et al. [KU 21]. give a thorough analysis of several AGC models in various power system topologies. The AGC systems' use of FACTS equipment’s, HVDC connections, and fast-acting energy storage devices are being examined. Franklin et al. [RFRF 22] focused on the structural examination of LFC, recent improvements

in control techniques, soft-computation methodologies, the integration of renewable energy sources with FACTS, and LFC in microgrid systems. Balvender Singh et al. [BS 23] reviewed how computational methods could be used to regulate the power system's frequency in single or multiple regions involving traditional, hybrid, and renewable energy sources. It also included FACTS devices and particular devices for storing energy, such as battery sources and SMES.

An optimized controller (OC) outperforms a PI regulator tuned by an ACSA when examining a reorganized two-region, four-section thermal structure. The power system models incorporate fast-responding energy storage units, including RFBs, and their effectiveness in improving AGC performance is tested and evaluated [YA 17]. To give the turbine controller an extra control variable, Mishra et al. [RNM 24] proposed constructing new AGC controllers that take DC tie-line power variation into account. In every control region, there are two power distribution corporations (DISCOs), three thermal generations, one steam and two hydroelectric combined, and three hydroelectric generations. Add redox flow batteries (RFB) to enhance additional dynamic outcomes and the stability margins of the suggested systems.

In a reorganized electricity market, Sandeep Bhongade et al. [SB 10] suggested an ANN-based frequency regulator architecture for multi-region AGC. Model development additionally considered the Superconducting Magnetic Energy Storage (SMES) unit effect. Power systems use SMES units to inject or absorb active power. Dilip Khamar et al. [DK 20] proposed a hTLBO-PS method with a TID regulator for an unregulated AGC. Dual-stage PI–PDF regulators appear in the tie-line at each location to improve system performance for a combination of two-region energy infrastructure models that includes steam, hydroelectric, gas, breeze, and sunlight sources. Transient power variations are handled by SMES devices in both sectors. Thermal governor models use governor dead-band (GDB), and thermal and hydro turbine models use generation rate constraint (GRC) to assess system nonlinearity [BS 22]. FOPID controllers and auxiliary gadgets such as SMES and UPFC in an unregulated atmosphere demonstrate the importance and effectiveness of a decentralized network. A new artificial intelligence optimization strategy has been proposed to increase the electrical system's reliability by optimizing the FOPID controller. SMES and UPFC devices significantly reduce frequency and tie-line power fluctuations [DKM 22].

When the use of renewable energy increases, energy storage devices become more significant because they can store renewable electricity in low-traffic times and return it to the grid during times of high demand. Thus, good ESS device placement provides unique steady-state power flow regulation and dynamic stability management [MRC 22]. A novel H2 filter design method that considers common Communication Delays (CDs) maximizes the distribution of FR signals among traditional and fast-regulating ESS assets, according to Cañizares et al. [NSGE 22]. In order to examine the effects of these ESSs, CDs, and constrained regulation capacity on the FR process in a real system, this filter is then integrated into a validated FR model of the OPS with Battery and Flywheel ESSs.

Yiqiao Xu et al. [YX 23] presented a unique technique called Optimization-based Ramping Reserve Allocation (ORRA) to solve a persistent challenge in the development of AGC, namely the best possible coordination of multiple BESSs. The proposed scheme illuminates the energy-neutral operation, which is realised by fully exploiting the synergy between slow ramping resources and BESSs while simultaneously smoothly ceasing the BESS participation and minimizing AIE, a variant of the traditional Area Control Error (ACE). With the current high rates of new energy penetration, battery energy storage systems (BESS) have emerged as a valuable tool for enhancing power grid frequency control performance. To address the problem that the current control strategy is insufficient for allocating the frequency regulation power instructions, Bingqing Yu et al. [BY 22] propose a hierarchical distributed coordinated control strategy for BESS to participate in the AGC of a regional power grid. Muhammad Abdillah et al. [MA 23] suggested a novel PID regulator for BESS for multi-area non-reheat thermal power to improve frequency dynamical performance. The simulation results suggest that a PID controller may improve BESS response and reduce frequency variations more successfully.

Naledi Ram Babu et al. [NRB 22] offer a comprehensive literature review and large documentation on AGC/LFC analyses. The study highlights various control viewpoints regarding power and frequency control. Under traditional and unregulated regimes, different linear and non-linear electrical network models are discussed, taking into account a range of power-generating origins, including traditional, sustainable energy sources (SES) and actual SES. In order to find the optimal parameters of FO-PID load frequency management integrated with an interlinked network that includes sustainable energy

sources, Ahmed Fathy et al. [AF 22] offer a contemporary skill optimization technique. The goal is to reduce exchange power violations and the integral time absolute error of frequency. Zahid Farooq et al.[ZF 23] are looking at the dynamic control of a combination of unregulated electrical systems based on SES. Several secondary controllers were successfully optimized by applying the satin-bowerbird optimization (SBO) method. It is discovered that the cascaded ID-PD controller's system dynamic responses significantly increase the power system's dynamic stability. Mohammed Khudhair et al. [MK 22] developed a new combination controller, the PIDD2-PD, to improve the frequency responsiveness of a multi-region-linked power system with numerous producing units connected to it. This work demonstrates the proposed controller's resilience to various load fluctuations (step, random, and multi-step), the insertion of sustainable energy sources, and network variable modifications through the application of numerous and varied scenarios. Sandhya Kumari et al. [SK 22] investigated the operation of a lesser-known FO-based CTI-TID regulator for time-domain simulation-based LFC of interlinked restructured electrical systems with nonlinearity. The impact of CESS on the relevant RPS model is examined.

Diem-Vuong Doan et al. [DVD 23] conducted a comparison analysis to assess the efficacy of the suggested PID-like fuzzy logic controller. The fuzzy-PID regulators investigated have been validated on a two-region steam power structure, taking into consideration the physical limits of the GRC, GDB, and renewable energy supplies to produce realistic results. Nayak et al. [SRN 23] introduced a novel SCaAVOA for a TID regulator structure to regulate the frequency of a mixed five-zone electrical system. The mixed system takes into account a few nonlinearities, like dead band and GRC, in addition to a range of traditional and unconventional inputs. For the AGC of two domains, hybridized traditional and clean energy sources, Amil Daraz et al. [AD 23] built and created a FOPID regulator and its modified structure, known as an MFOPID regulator, with the addition of several nonlinearities like GDZ, BD, CTD, and GRL. Ping Wang et al. [PW 24] introduced an LFC technique based on optimal parameter optimization and FOPID controller tuning to deal with frequency variation concerns in an IPS, including sustainable energy-producing units.

Shubra Goel et al. [SG 22] review the AGC strategy in wind power generating units, battery energy storage systems, and microgrids. SA, fuzzy reasoning-based optimization, PSO, GA, ACO, and ANN-

based optimization have been investigated. Additionally, PV power station AGC application and EV operation have been explored. Hossein Shayeghi et al. [HS 22] developed a master-slave PDDN-Iλ controller for linked MG frequency regulation. The JAYA algorithm is used to optimize system settings to improve control. The investigation focuses on sudden load variations in both domains, unit output variations based on RESs, and uncertainty in system fundamental parameters. Studies were done with and without EVs. The LFC investigations of three steam region systems have called for the creation of a real-time simulation lab. Systems related to wind and heat are connected in regions 1 and 2. A cascade TI-PID accessory controller with the crow search method is proposed [NRB 23]. Vishwas et al.'s study from [VB 23] examines a hybrid system that combines solar power, a biodiesel engine generator, a combined sunlight-powered gas turbine, and energy storage. Case studies and research have evaluated DBOA-optimized PID controllers.

A distinct blend to enhance a two-region interlinked electrical structure's frequency responsiveness, Moetasem Ali et al. [MA 22] successfully suggested a fuzzy FOPI + TID controller. Power plants that do not require non-reheat or hydroelectricity are combined with sustainable sources of energy like sunlight and wind energy to create a combined power system. Moreover, the frequency and tie-line power changes are improved by the existence of EVs. A unique T2FI$^{\lambda}$D$^{\mu}$-P regulator is proposed by Pulakraj Aryan et al. [PA 22] for the purpose of regulating the load frequency of a two-region unregulated PS that has several producing units, including green energy. The PS-producing units that are being examined are gas, steam, and distribution of renewable energy sources like solar PV and wind turbine electricity. Using the equilibrium optimizer, the recommended T2FI$^{\lambda}$D$^{\mu}$-P controller is ideally tuned. Nisha Kumari et al. [NK 23] recommend a T2FID+PD regulator adjusted with AVOA for a 3-region unregulated electricity infrastructure. It shows how the integration of EVs and fluctuation in distributed renewable generation affect the system's dynamics. Because of the uncertainties involved in multi-area power systems, which include steam and distributed sustainable power generation sources like sun and wind power, an efficient load frequency control (LFC) technique is needed. Consequently, a new T2FPD + 2DOFPID is developed. EVs and DRG units can enhance their dynamic responses during high-demand periods by serving as energy storage components [NK 23]. Abhishek Anand et al. [AA 22] provide a T2PD+I regulator tuned via AO applying the ITSE objective function for a 2-region

reorganized electric system. Whereas connected thermal and gas units are located in Area 2, area 1 of the PS under consideration for inquiry consists of distributed generation (DG) sources and electric vehicles (EVs). Plug-in electric cars (EVs) enhance system dynamics.

According to Hiramani Shukla et al. [HS 24], the challenge lies in integrating AGC and AVR for an integrated hybrid system that comprises electric vehicles, traditional thermal units, and renewable energy sources like solar thermal, wind, and photovoltaic electricity. The AGC and AVR system oscillation is suppressed using a new cascade fractional order (FO) regulator called FO PID-FO PD (cascade $PI^{\lambda}D^{\mu}$-PD^{μ})—a modern optimization method known as the Coot algorithm is used to calculate the controller's parameters. In a deregulated situation, Sandeep Rangi et al. [SR 24] highlights an attempt to compare the performance of multiple hybrid energy storage systems (HESSs) for the AGC of multi-area multi-source power systems. A two-region DPS with thermal, hydro, and gas (THG) producing units in each area makes up the system under consideration. The performance of a cascade optimal controller-fractional order derivative (COC-FOD) is compared to that of an optimal controller (OC) to improve AGC performance. The secondary FOD controller gains are optimized using a nature-inspired salp swarm algorithm (SSA), while the primary OC is created using a complete state feedback control technique.Tian Tian et al.[TT 24] concentrate on the hydraulic turbine regulating system's controller design and parameter optimization. First, they use fractional calculus and second-order derivative to propose a fractional-order PID plus second-order derivative (FOPID2D) controller. They subsequently present a modified strength Pareto evolutionary algorithm II (MSPEA2) for multi-objective optimization design that uses the Uniform–Cauchy–Gaussian hybrid mutation operator. The test function results show that MSPEA2 produces wide-distribution, high-quality non-dominated solutions. Evaluation indicators, including rise time, peak time, and peak value, compare the FOPID2D, PID, fractional-order PID, and PID plus second-order derivative controllers. According to the results, FOPID2D outperforms the other traditional controllers regarding speed and objective function values.

Fuzzy-logic-based controllers (FLCs) of the Type-I variety are gradually gaining traction in AGC applications. The complexity of Type-I fuzzy system depends on no. of variables, no. of fuzzy sets, shape and overlapping of membership functions, no. of rules, large memory requirement and time intensive. However, Type-II polar fuzzy system is better than Type-I fuzzy system, which can include

uncertainties of experts' response in the field of AGC for the development of membership function of fuzzy sets. Type-II polar fuzzy system can better handle dynamic changes in deregulated power system; therefore, it is recommended for AGC over Type-I fuzzy system. It gives flexibility in responding to load variations, market swings, and disruptions typical of deregulated situations by permitting a range of membership values. Accuracy in managing nonlinear dynamics, preserving system stability, and minimizing errors are all enhanced by this flexibility.

Research Gap

1. A lot of research work has been done on Type-I FLC for AGC of deregulated power systems in the past, but the complexity of Type-I FLC is higher and therefore, the real-time responses are slower. Hence, it is needed to simplify type – I FLC with a polar fuzzy logic controller. but as per the researcher's knowledge there is no work done in the area of polar fuzzy system to control the deregulated power system under different operating conditions which is depends on the Disco Participation Matrix (i.e Poolco, bilateral, Contract Violation conditions).

2. Type-II fuzzy system is better than Type-I fuzzy system, which can include uncertainties of experts' response in the field of AGC for the development of membership function of fuzzy sets. However, earlier researchers also did not attempt the Type-II polar fuzzy system for a deregulated power system.

3. There is no work done in the past on Type-II Polar fuzzy system for AGC in a deregulated power system and its performance Optimization.

4. In the literature survey the research could not find an adaptive Type-II Polar fuzzy system for AGC in a deregulated power system.

5. The deregulated power system includes the renewable energy sources and different energy storage devices in the modern time and impose new challenges on AGC using adaptive Type-II Polar fuzzy system.

Objectives of Research Work

Automatic generation control (AGC) is crucial for decreasing dynamic oscillations and preserving frequency and intended tie-line power constancy, which helps to ensure the trustworthy, safe, and stable functioning of electrical energy systems in changing circumstances. To achieve generation-demand balance in today's complicated structured energy networks in response to unforeseeable load demands,

AGC requires energy storage systems (ESS) as well as more competent, sophisticated, and flexible control mechanisms. The frequency of the system and tie-line flow deviates from their prescribed values due to unforeseeable fluctuations in customer power demand, resulting in discrepancies between generation and demand in the reorganized power systems. To achieve above mentioned purpose the proposed research work is divided in the following primary objectives:

1. To reduce the complexity of Type-I Fuzzy system a polar fuzzy system is design to control the deregulated power system under different operating conditions which is depends on the Disco Participation Matrix. (i.e Poolco, bilateral, Contract Violation conditions)

2. To design and develop Type – II polar fuzzy AGC to minimise electrical deregulated power system frequency deviation and tie-line power flows between different areas.

3. To develop an optimized Type - II polar fuzzy system for AGC.

4. To develop an adaptive Type-II polar fuzzy system for AGC in a deregulated power system using learning mechanism.

5. To use proposed controller for the combination of different types of generations such as conventional as well as renewable energy generations which incorporate different energy storage devices.

Flow Chart

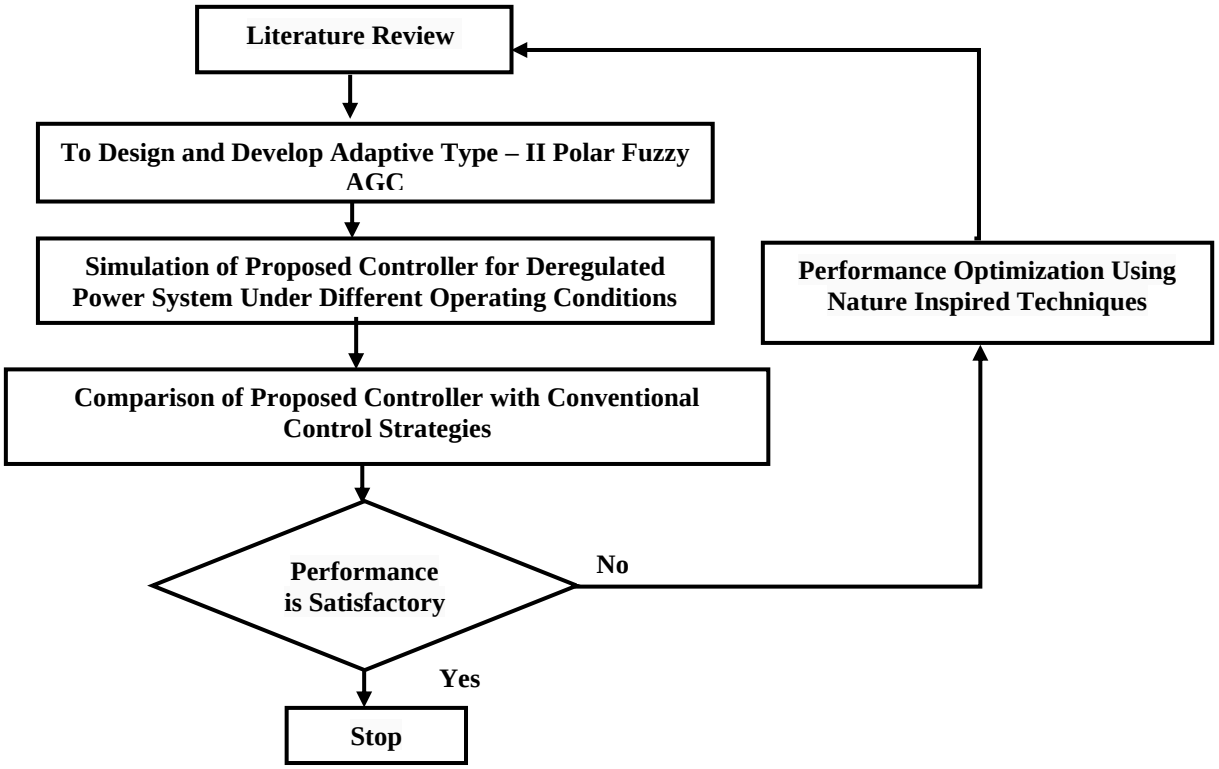
Literature Review
To Design and Develop Adaptive Type – II Polar Fuzzy AGC
Simulation of Proposed Controller for Deregulated Power System Under Different Operating Conditions
Comparison of Proposed Controller with Conventional Control Strategies
Performance is Satisfactory
No
Yes
Stop
Performance Optimization Using Nature Inspired Techniques

Fig. 3 Flow Chart

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